bandwidth limiting factor is mode conversion from a low order mode to the next higher mode caused by discontinuities or irregularities along the waveguide. (Implicit in the following analysis of waveguide systems is the assumption of single, upper-sideband modulation with or without carrier suppression.)

Figure 8 is a plot of attenuation vs. frequency in a rectangular waveguide 100 according to the present invention. It can be seen from Figure 8 that the lowest operating frequency, f_0, that avoids severe attenuation near cutoff is approximately twice the TE 1,0 cutoff frequency, f_c, or

$$fc < f_0 \leq 2*(c/2a) = c/a \qquad (4).$$

The cutoff frequency for the TE 3,0 mode, which is the next higher mode because of gap 112, is three times the TE 1,0 cutoff frequency or

$$f_m = 3*(c/2a) = 1.5*f_0 \qquad (5).$$

The bandwidth, BW, based on the upper sideband limit, is then (f_m-f_0), which, on substitution for c, the speed of light, is

$$BW = 150\ (Ghz*mm)/p, \qquad (6)$$

where p, the data channel pitch, has been substituted for a, the waveguide width. Again, b/p is defined to be less than 0.5 to suppress TE 0,n modes. The bandwidth density, BWD, is simply the bandwith divided by the pitch or

$$BWD = BW/p = 150 / p*p\ \ (Ghz/mm) \qquad (7).$$

Then the relationship between BW and BWD is

$$BW = (150*BWD)^{0.5}\ (Ghz) \qquad (8).$$

A plot of this relationship, corresponding to a frequency range of, for example, about 20 GHz to about 50 GHz, is shown relative to the bandwidth vs bandwidth density performance of a "SPEEDBOARD" backplane in Figure 9. It can be seen from Figure 9 that the bandwidth and bandwidth-density range obtainable with the rectangular TE 1,0 mode backplane system is approximately twice that of the "SPEEDBOARD" system.

Figures 10-12 also demonstrate the improvement that the present invention can have over conventional systems. Figure 10 provides the attenuation versus frequency characteristics of conventional laminated waveguides using various materials. Figure 11 provides the attentuation versus frequency characteristics of a backplane system according to the present invention, specifically a 0.312" by 0.857" slotted waveguide using a 0.094" diameter copper tubing probe with 5h / 8 penetration at λ_0 / 0.4 GHz. Figure 12 provides the attenuation versus frequency characteristics of another backplane system according to the present invention, this time using a doorknob-type antenna.

These figures demonstrate that the waveguides of the present invention have greater relative bandwidth than conventional systems.

Although described in this section as an "air filled" waveguide, the present invention could use filler material in lieu of air. The filler material could be any suitable dielectric material.

<u>NonRadiative Dielectric (NRD) Waveguide Backplane System</u>

Figure 13A shows a conventional TE mode NRD waveguide 20. Waveguide 20 is derived from a rectangular waveguide (such as waveguide 10 described above), partially filled with a dielectric material, with the sidewalls removed. As shown, waveguide 20 includes an upper conductive plate 24U, and a lower conductive plate 24L disposed opposite and generally parallel to upper plate 24U. Dielectric channel 22 is disposed along a waveguide axis (shown as the z-axis in Figure 13A) between conductive plates 24U and 24L. Dielectric channel 22 has a width, a, along the x-axis and a height, b, along the y-axis, as shown. A second channel 26 is disposed along waveguide axis 30 adjacent to dielectric channel 22. U.S. Patent Number 5,473,296, incorporated herein by

reference, describes the manufacture of NRD waveguides.

Waveguide 20 can support both an even and an odd longitudinal magnetic mode (relative to the symmetry of the magnetic field in the direction of propagation). The even mode has a cutoff frequency, while the odd mode does not. The field patterns in waveguide 20 for the desired odd mode are shown in Figure 13B. The fields in dielectric 22 (*i.e.*, the region between -a/2 and a/2 as shown in Figure 13B and designated "dielectric") are similar to those of the TE 1,0 mode in rectangular waveguide 10 described above, and vary as Ey ~ cos(kx) and Hz ~ sin(kx). Outside of dielectric 22, however, in the regions designated "air," the fields decay exponentially with x, *i.e.*, exp(-τx), because of the reactive loading of the air spaces on the left and right faces 22L, 22R (see Figure 13A) of dielectric 22.

The dispersion characteristic of this mode for a "TEFLON" guide is shown in Figure 14, where Beta and F are the normalized propagation constant and normalized frequency, respectively. That is,

$$\text{Beta} = a\beta/2 \qquad (9)$$

and

$$F = (a\omega/2c)(Dr - 1)^{0.5}, \qquad (10)$$

where c is the speed of light, and Dr is the relative dielectric constant of dielectric 22. The range of operation is for values of f between 1 and 2 where there is only moderate dispersion.

Since the fields outside the dielectric 22 decay exponentially, two or more NRD waveguides 30 can be laminated between substrates 24U, 24L, such as ground plane PCBs, to form a periodic multiple bus structure as illustrated in Figure 15A. As shown, the bus structure can include a plurality of dielectric channels 22, each having a width, a, alternating with a plurality of air filled channels 26. The dielectric channel 22 and adjacent air-filled channel 26 have a combined width p. The first order consequence of the coupling of the fields external to dielectric 22 is some level of crosstalk between the dielectric waveguides 30. This coupling decreases with increasing pitch, p, and frequency,